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University of Kentucky

AN ANALYSIS OF CLOVER FAILURE IN KENTUCKY

BULLETIN NO. 324
(RESEARCH BULLETIN)

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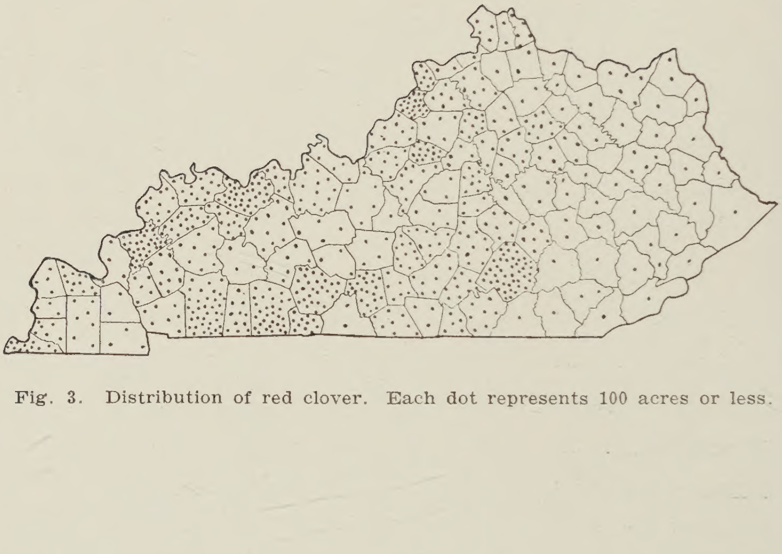

Fig. 3. Distribution of red clover. Each dot represents 100 acres or less.

BULLETIN NO. 324

(RESEARCH BULLETIN)

An Analysis of Clover Failure in Kentucky

E. N. FERGUS*

HISTORY OF RED CLOVER IN KENTUCKY

Red clover (*Trifolium pratense* L.) was brought to central Kentucky about 1803 from Pennsylvania. In a few years after its introduction the crop was rather widely grown, and practically every farmer saved his own seed (37). No records have been found of its first introduction into other sections of the state. However, since agricultural development in the central part of the state preceded that in the western part, it seems safe to assume that the clover brought into central Kentucky in 1803 was the first red clover grown in the state. With the exception of this difference in priority, the general history of the crop has been similar in both parts of the state.

For twenty-five or thirty years farmers in central Kentucky produced their own clover seed, according to Spurr; then northern seed began to replace it, and in a few years home seed production was almost abandoned. Subsequent references to the crop in central Kentucky give no suggestion that seed was ever again regularly produced by most farmers, altho its production by individual farmers was not unusual (30).

Probably most northern seed sold in central Kentucky about 1830 was produced in Indiana, Ohio, Michigan, and states farther east. Seed from more western states north of the Ohio river was introduced later. European seed was first sold in Kentucky about 1900, according to farmers and seedsmen. Since

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*Dr. W. D. Valleau, plant pathologist of the Kentucky Agricultural Experiment Station, gave generous and invaluable assistance thruout these studies, especially in identifying diseases and evaluating their importance.

1900 Kentucky has obtained its supply of clover seed from Europe, Chile and parts of the United States having a surplus. Seed from Idaho, Oregon and Washington seems not to have reached Kentucky markets until after 1910.

While Kentucky farmers as a group have obtained much or most of their seed outside the state for nearly a century, inquiry has shown that a few farmers have regularly produced their own seed since 1890 and others since later dates; therefore it is reasonable to suppose that the practice has been followed by some farmers from the time that clover was introduced. Whether any of the present stocks in Kentucky trace back to original early introductions cannot be ascertained, but it is probable that they do in some instances, where sons have followed the practice of their fathers in the saving of seed.

Two practices of fundamental importance have been followed by some farmers who regularly produce their own supply of clover seed. First, they save seed every year it is possible, even tho the yield may be low or harvesting difficult. Second, a reserve of seed is maintained so that in case of failure seed will be available for sowing the next crop. The first practice has resulted in rapid and rigorous natural selection, and the second has maintained the purity of the variety.*

According to census reports, red clover reached its largest acreage in Kentucky about 1899, with 158,110 acres. In 1909 it was 76,974 acres, and in 1919, 107,266 acres. However, it may be that this does not represent an actual increase in red clover, but rather an expansion of the acreage of other legumes popularly called clovers, a trend that began in 1906 because of red clover failures (13). The 1924 census data support this interpretation, since out of a total clover area of 94,371 acres there were only 72,300 acres of red, mammoth and alsike clovers. The 1929 census lists 114,777 acres of red, mammoth and alsike clovers, which indicates a large increase in red clover acreage, but it is known that the 1929 clover crop was unusually large. It is

*"Variety" is applied thruout this paper to a clover which possesses definite homogeneity for adaptation. Accepted nomenclature in corn furnishes a precedent for doing so, tho it is recognized that there are good reasons against such use of the term. However, since it is a category with which farmers are familiar, it is believed that its application to such clovers will hasten adoption of them in preference to those of unknown value.

believed that the 1924 figure is more nearly correct for the average acreage. There is little question, therefore, that the Kentucky red clover acreage now is less than half of what it was about thirty years ago.

According to Spurr (37), clover was a luxuriant crop in central Kentucky until the farmers began to purchase northern seed; then the crop became less productive. It appears that it was still grown easily until about 1900, however, when failures became quite frequent. Farmers state that these failures caused the decline in acreage after that date, and since the failures and the date are matters of record (12) there can be little doubt of the correctness of the farmers' explanation.

A study of the cause of clover failures was one of the purposes for which experiment fields were established on representative soil types in Kentucky between 1909 and 1917. Results obtained from these fields by 1920 (34) showed that while applications of lime, manure, and phosphate greatly increased clover yields outside the Bluegrass region, they alleviated rather than remedied the situation, as failures continued to occur on even the best soils. Therefore, a specific investigation was undertaken to determine the cause or causes of red clover failures in Kentucky.

METHODS OF STUDY

Since seed of most of the clovers grown in Kentucky is obtained outside the state, it was recognized that any adequate investigation of clover failures must be based upon a knowledge of the reaction of these clovers to Kentucky conditions; consequently the studies, from the beginning, included observations of clovers from different regions, growing under similar field conditions.

Many of the domestic and most of the foreign clovers studied were furnished by Drs. A. J. Pieters and E. A. Hollowell, of the United States Department of Agriculture; the remainder were obtained by the writer. The latter were cleaned and then tested for purity and germination by the seed laboratory of the Kentucky Agricultural Experiment Station. The lots usually were sown in duplicate, on 1/80-acre plots. Check plots were

used, but their frequency varied from year to year. Most tests were spring-sown in wheat on land that had been harrowed lightly; two were August-sown on bare fallow. All but two tests (1924-25 and 1926-27) were sown on soil which had received about two tons of ground limestone to the acre some years previously. The seed was mixed with damp sand to enable more even distribution, and sown by hand at rates, varying with the test, of 10 to 14 pounds of viable seed to the acre. No space was left between plots.

Notes on stand, vigor, and diseases were taken as soon as the wheat was harvested, and further observations were made from time to time until the end of the second summer. Stands were determined by counting the plants in a few representative areas in each plot. The plot having the best stand in the initial counts in each test was rated as 100. Since duplicate plots seldom had equal stands, few clovers are reported with 100 percent stands. Hay yields were obtained in various ways. Because the poorer plots in 1927, 1928 and 1929 contained many weeds, representative areas totaling 2 to 5 square meters were cut by hand, weeds and clover separated, and the clover weighed green. In 1930, when the plots were relatively free of weeds, whole plots were harvested. All or a part of the harvested clover was loosely bagged and air-dried in a hot room. The moisture content of the dry material was determined by drying portions to constant weight in a drying oven at 110° C.

GENERAL RESULTS OF THE TESTS

Early studies showed that some environmental factors were distinctly unfavorable to some clovers while less so to others, but little progress was made in their identification until an adapted clover was obtained and included in the tests. This variety (Kentucky 101), first sown in 1926, along with a number of other promising Kentucky clovers, has shown its superiority to ordinary commercial lots from the first, and has been used as a standard by which to measure the adaptability of other lots. Contrasts between it and other lots, in reaction to unfavorable factors, have made it easier to determine the causes of clover

failure and to arrive at some conception of the relative importance of each.

These studies have shown that clover failures are the result of a series of adverse environmental factors acting upon clovers susceptible to them. One or more of these factors may cause injury during the first summer after seeding, while others may cause injury during the winter, second spring and second summer; at other times the first injury may occur during the winter or later critical periods. Usually each factor destroys a portion of the stand, tho occasionally a single factor kills practically a whole stand. These differences in susceptibility to causes of failure usually appear to be due primarily to a heterozygous condition of most clovers, as few of those tested, except European and, possibly, Chilean, appear to be relatively homozygous in degree of susceptibility. Most clovers react as hybrids of widely different physiological parents or as mixtures of two or more lots of different adaptations, a situation to be expected because of the commercial practice of seed mixing (2, 31). It is apparent, therefore, that clover failures may vary in extent from complete to slight, and in time of occurence from the first summer to the second summer. Clovers which are completely destroyed are considered unadapted and, by contrast, those clovers which are so highly resistant that, when properly managed, they consistently produce good crops and an aftermath in the second year are considered as being adapted.

The clover-failure problem is complex and perhaps some factors involved have not yet been discovered, either because they have been absent from our tests or because they were not recognized. Since the effects of different factors often overlap in time, it is frequently difficult to determine all that are present and which is actually causing the greatest mortality of plants. It is especially difficult to determine the effect of a factor which enters after another has been operating for some time.

CAUSES OF CLOVER FAILURE IN KENTUCKY

The recognized factors contributing to clover failures in Kentucky include soil deficiencies, parasitic diseases, winter-

killing, and leaf-hopper injury. There seem to be only a few parasitic diseases of red clover which contribute to clover failures in Kentucky, but one or more of them usually are present at some time during the life of most crops. Those which have been recognized are southern anthracnose (*Colletotrichum trifolii* B & E), northern anthracnose (*Gloeosporium caulivorum* Kirch), crown rot (*Sclerotinia trifoliorum* Erik), *Rhizoctonia*, root rots, and "black stem."

The *southern anthracnose* was present in Tennessee in 1905 (5), where it undoubtedly had caused extensive losses of clover stands, at least since 1896 (32). It was at once recognized thruout the southern part of the clover area, and soon thereafter somewhat farther north. Since then it has been found in practically all clover-growing states of eastern United States except New England (25).

The seriousness of this disease evidently was not recognized outside of Tennessee until about the middle of the last decade (33). The date of the first appearance of the disease in Kentucky is not known. Probably it has been here as long as in Tennessee. Undoubtedly it caused some of the failures which were becoming frequent in 1902.

In these tests the disease was identified as contributing to clover failure for the first time on July 23, 1928, when it was found to be rapidly destroying a first-year Michigan clover. It was later well distributed thru the clovers. The situation in 1929 practically duplicated that of 1928, as the disease was observed first on July 17, in an Indiana clover. Before late fall it was found on plants in practically all clovers, including Tennessee anthracnose-resistant and Kentucky 101.

Since the disease affected practically all clovers from a given region similarly, the averages are indicative of the extent of clover failures which it causes in Kentucky under favorable conditions. Excluding European clovers from present consideration, since the disease was a dominant factor in their failures in 1929 only, it is evident from the data given in Table 1 that this factor is most destructive to northwestern domestic clovers and successively less injurious to northern, central,

southern, Tennessee anthracnose-resistant, and adapted clovers represented by Kentucky 101. The data from the two tests show that it destroyed clovers in these groups to the extent of about 79, 66, 47, 34, 25 and 7 percent, respectively. The 1929 data given in Table 1 show that this disease injures European clovers approximately to the same degree as northern domestic lots.

TABLE 1. Effect of Colletotrichum trifolii B & E on stands of red clover.

Clover*	Crop 1928-1929 Stand**		Crop 1929-1930 Stand**	
	Original	11/7/28	Original	12/11/29
		Percent		Percent
Kentucky 101		90		95
Tennessee	(1)† All excellent	90	(3)† All excellent	60
Southern	(21)	64	(52)	67
Central	(7)	50	(5)	56
Northern	(6)	23	(6)	42
Northwestern	(6)	10	(12)	31
Russian		Stands of foreign clovers in this test reduced primarily by potato leaf hopper.	(1)	45
German			(3)	40
French			(4)	38

*"Northern" clovers refers to those from Canada, Michigan, Minnesota, Wisconsin, and Iowa; "northwestern" clovers to those from Oregon, Washington, and Idaho; "central," to those from Ohio, Indiana, Illinois, and Missouri; "southern" clovers are those from Maryland, Virginia, Kentucky (except Kentucky 101), and Tennessee (except the Tennessee anthracnose-resistant variety). Tennessee refers to the anthracnose resistant variety.

**90 stand = 67 plants to the square meter in 1928-29 test and 95 stand = 102 plants in the 1929-30 test.

†Figures within ( ) indicate number of lots averaged.

The data in Table 1 indicate that southern anthracnose affects French more than German and Russian clovers, tho the difference is of little agronomic importance. Evidence regarding injury to Italian clovers is insufficient to permit a definite conclusion, since only one plot was available for observation in 1929, and it was in a different study from other clovers listed in Table 1. Apparently, however, the disease is more destructive to Italian clover than to French and less than to some north-

western clovers. This is in agreement with observations of Mains (22).

Southern anthracnose is not equally destructive to all clovers produced in a given region. Even among northwestern clovers, which are on the average practically destroyed, an occasional lot is only moderately affected. One such clover obtained from Professor George Hyslop, of the Oregon Agricultural College, and included in the 1929 seeding was detroyed only to the extent of 40 percent. The greatest variation in injury occurs among southern-grown clovers, however, where the range is from practically total destruction of stand to slight or no injury.

The southern anthracnose apparently is not always present in clover fields in Kentucky, possibly because much of the seed is from regions where the disease is not common. If it were, failures or partial failures would be still more common. Climatic conditions even in central Kentucky are usually favorable to the disease, as a comparison of favorable temperatures for the disease with summer temperatures clearly shows. Monteith (24) found that organism grew rapidly on four media at from 12° to 32° C. (53.6° to 89.6° F.) Spores were formed at 20° to 32° C. (68° to 89.6° F.) The normal daily temperatures of central Kentucky, which are graphically presented in Fig. 1, are therefore favorable for its growth from April 15 to October 25, and for spore formation from May 27 to September twentieth. The normal daily temperature at Lexington from July 4 to August 10 is 76° F., which is essentially the temperature that Monteith found highly favorable for spore germination and infection. Normal daily summer temperatures in western and southern Kentucky are approximately 3° F. higher than at Lexington and are favorably for the disease.

Southern anthracnose therefore greatly contributes to clover failures in Kentucky because it is frequently present and is highly pathogenic, under normal Kentucky environment, to almost all red clovers which Kentucky farmers sow. Probably, however, the high resistance of Kentucky 101 is the best evidence that the disease has been a critical factor of clover environment

in the state. Since this variety is the product of many years of natural selection, it is believed that any cause of injury to which it is resistant has contributed to clover failure in Kentucky. While there is a possibility, of course, that such resistance may have been acquired in its previous environment and therefore does not indicate a cause of failure in Kentucky, it seems quite unlikely that the variety would have remained so nearly homozygous for resistance thru its many generations in Kentucky if the factor were not critical in its present environment.

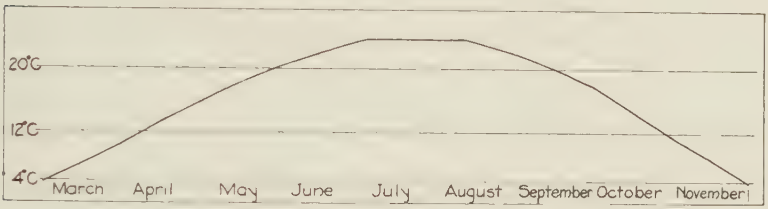

Fig. 1. Normal daily temperature at Lexington. From the U. S. Weather Bureau records.

Obviously this interpretation lacks the support of sufficient direct evidence and must do so until a known variety can be studied for varietal stability under a new environment. It claims the support, however, of logical genetics in heterozygous plants.

The lesser resistance of the Tennessee clover to the southern anthracnose as compared with Kentucky 101 in these tests might be considered as invalidating the assumption that resistance of a Kentucky variety to a critical factor denotes that that factor contributes to clover failure in Kentucky, but the histories of the two varieties probably explain the difference. Bain and Essary (5) apparently made their initial selections in 1905 in susceptible clovers, as most of the plants were killed by the disease. Kentucky 101, on the other hand, began its known history in 1907, when it must have been well adapted, as it was already resistant to some unknown factor which killed another clover in the same field. In other words, Kentucky 101 probably was resistant to the disease before selection of the Tennessee anthracnose-resistant clover was begun.

Northern anthracnose (*Gloeosporium caulivorum* Kirch), another contributing factor to clover failure in Kentucky, is of undetermined origin. Kirchner (20) who described the causal organism, credits Mehner with its discovery in Europe in 1901. It was in the United States in 1903, tho not reported until 1906 (39).

The disease is regarded as serious in parts of northern and central Europe (6, 21), where studies show that it damages clovers from France, Italy, Switzerland, and the Baltic regions of Russia, moderately injures those from Germany and Austria, and slightly affects those from southern Russia, Poland and Bohemia. Red clovers from northeastern America were much damaged in limited tests; those from northwestern America moderately injured; and Canadian clover slightly affected.

Apparently the disease is not considered serious in the United States, altho Van Pelt (43) regards it as important in Ohio, and Stewart (39) observed it causing heavy losses in yield in New York. It apparently injures southern European more than domestic clovers in northern United States, but the evidence regarding this is meager and somewhat conflicting (1, 23, 28, 46).

This disease occurred destructively but once in these tests. It was first noticed on May 25, 1927, in the 1926-27 crop, where three of nineteen southern clovers were damaged severely and nine others, southern and central clovers, were injured appreciably. Five southern, and all northwestern and northern domestic clovers were free and appeared to be resistant. It probably reduced the first-crop hay yield of the most severely affected southern clovers about 13 percent, as shown by the data in Table 2, since these and the uninjured Kentucky 101 had equal stands and appeared equally productive before the disease developed. Not only was the first crop reduced in yield, but the hay was poor in quality because of dead stems and loss of leaves. The disease was not observed in the second crop, consequently the 44 percent lower hay yields of the previously affected clovers, as compared with Kentucky 101, indicate its injury to stands of susceptible clovers.

Little significance can be attached to the lack of injury by northern anthracnose on most clovers in this test because the disease was unevenly distributed in the test field. Kentucky 101 appears to be resistant, however, as the disease, which was

TABLE 2. Effect of Gloeosporium caulivorum Kirch. on yield of red clovers.

Clover	Stand* 3/21/27	Hay Yields, Kentucky 101 Taken as 100	
		First Crop	Second Crop
	Percent		
Kentucky 101	90	75	25
Tennessee 2640	90	66	14
Virginia 2531	90	69	14
Virginia 2575	90	61	14

*90 percent = about 335 plants to the square meter.

severe in Virginia 2575, ended abruptly at the border of the Virginia clover where it joined Kentucky 101. The extent of the injury on European clovers could not be determined definitely because of their previous severe injury by the black-stem disease. French, Roumanian and Hungarian clovers were injured, tho less than the severely affected southern domestic lots.

The injury caused by northern anthracnose to clovers in these tests proves that the disease contributes to clover failure in central Kentucky. Since Kentucky 101, which is a product of central Kentucky, has undoubtedly acquired its resistance to the disease thru natural selection, it seems that the disease often has been pathogenic to clovers in central Kentucky.

Since the Tennessee anthracnose-resistant clover has not acquired resistance to the disease, it is probable that northern anthracnose is unimportant in Tennessee. This suggests that it is also unimportant in parts of southern and western Kentucky. However, certain early and late summer temperatures apparently are favorable thruout Kentucky for the disease. According to Monteith (24), optimum growth of the organism occurs at 20° C., a temperature that is approximately normal in central Kentucky from the middle of May to the middle of June, as shown by Figure 1, and in western Kentucky, where early

summer temperatures are slightly higher, during the month of May. All other normal daily temperatures in central Kentucky from March 1 to December 1 (Fig. 1) are within the range of 4° C. to 32° C., which Monteith reports satisfactory for the growth of the organism. The same temperatures obtain in western Kentucky approximately from the middle of February to the middle of December. Conclusive evidence of the importance of northern anthracnose in southern and western Kentucky awaits identification of failures due to the disease or the discovery of resistance in adapted varieties which have been developed there.

Crown rot (*Sclerotinia trifoliorum* Erik) has been recognized as a cause of red clover failure in Europe since 1857 (14), but Arthur Young's (48) description of clover sickness in England suggests that this disease was in England in 1804. Apparently its European distribution is largely confined to England, Germany, Denmark, Sweden, and neighboring regions. The disease has been recognized since 1890 in America, where it is most common in western Oregon and in southern and eastern portions of the clover area of the United States (14). Crown rot can always be found during the spring on the Station farm at Lexington and has been observed during the same season in the western part of the state; consequently it apparently is always present and widely distributed, tho the injury it causes to clover varies from year to year.

Crown rot was widely distributed during the spring of 1930 in the 1929-30 test and contributed to the failure of many clovers. In order to obtain a measure of its injury to clovers, plants which had died recently were counted in representative areas in certain clovers on April 9 when the disease had apparently about ceased its activity.* The plants which had sclerotia within or near the crown or taproot were listed as dying from crown rot; the plants which were free of sclerotia were divided into two groups. The plants in one group, except for the absence of sclerotia, appeared identical with those that died from the disease; i. e., the crowns were dirty-brown in color

*The disease ceased its activity at least a month earlier than usual in 1930 because of an abnormally dry, warm spring.

and lifted easily and evenly from the taproots. The crowns of the plants in the second group were the same color as the others, but some effort was required to remove them from the taproot and the separation left a jagged tear. Plants in the first of the groups without sclerotia were listed as probably dying from crown rot, those in the second, as probably dying from some

TABLE 3. Relation of Sclerotinia trifoliorum Erik. to mortality in red clovers of different origins.

Clover	Stand of Live Plants on plots Studied*		Dead plants per sq. meter April 9, 1930, killed during late winter and spring by			Percentage loss in fall stand probably due to Sclerotinia
				Undetermined Cause		
	12/11/29	4/8/30	Sclerotinia	Probably Sclerotinia	Possibly Not Sclerotinia	
	Percent	Percent				
Kentucky 101	95	94	0	1	1	1
Tennessee 1	65	55	0	0	11	0
Indiana 2	75	50	10	4	5	18
Wisconsin 2	60	15	1	2	8	5
Oregon 1	35	2	4	2	6	17
Oregon 2	60	55	2	1	4	5
Oregon 3	30	25	4	1	0	16
Oregon 4	15	5	1	2	4	20
Idaho 3	30	15	7	5	5	40
Idaho 14492	35	25	2	1	5	9
Russian 15881	45	20	7	3	12	22

*95 percent = approximately 100 plants to the square meter.

other cause. There is little doubt that this disease killed the plants listed in the first two columns in Table 3, and it now appears probable that it killed the plants listed in the third column but that the crown and taproot separated with difficulty because the middle lamella material was resistant to the organism, a relation similar to that described by Valleau (41) between *Sclerotinia cinerea* and resistant varieties of plums. The relation of this disease to clover failure in Kentucky needs further study. Nevertheless it is apparent that Sclerotinia contributes to clover failure in Kentucky, since it killed from 5 to 40 percent of the Russian and northwestern and northern domestic clovers in one test. The Tennessee anthracnose-resistant clover apparently was not injured by the disease, and Kentucky 101 was only slightly injured. Unfortunately no informa-

tion was obtained regarding the effect of the disease on French clovers, as they winterkilled.

The conclusion that Kentucky 101 is resistant to *S. trifoliorum* is further supported by evidence from the soil fertility field on the Experiment Station farm. One of four series of plots is in clover each spring. Kentucky 101 was sown for the 1928-29 and the 1929-30 crops; commercial seed had been sown previously. Classes in Plant Pathology have searched in these blocks each spring for eight years for plants affected with Sclerotinia. They were always easily found in the clovers from commercial sources, but it was difficult to find specimens in the crops of Kentucky 101. The resistance of Kentucky 101 is additional evidence that *Sclerotinia trifoliorum* contributes to clover failures in Kentucky.

A *root rot* of clover, the cause of which is unknown, is associated with clover failures on the poorer soils of Kentucky (11). Similar diseases have been found in Ohio (49), near Washington, D. C. (32), and in southern Russia, the last having been ascribed to *Fusarium trifolii* Jacz. by Travin (40).

Clover plants on poor soils in Kentucky lose all or practically all of their root systems during the first summer and die during the summer, fall or winter. Those on good soils lose many small lateral roots during the first summer and all but short portions of the taproot and largest laterals during the second summer. Clover root rot, therefore, causes failure of clover stands on poor soils, where the loss of a few roots may constitute a relatively high percentage of root loss; but not on good soils, where root loss is insufficient to result in death of the stand before it has produced its two crops the second year.

This disease was not a deciding factor in any failures reported in this paper, as all tests were conducted on good soils. Root systems of different clovers were examined from time to time to time, but no significant difference in amount of rootlet injury was observed. The larger roots of Kentucky 101 were injured somewhat less than those of unadapted clovers, but this may have been due to the better general health of Kentucky 101, rather than any difference in resistance.

Adapted clovers tested so far have been developed as biennial crop plants on the better soils of the state, consequently the root diseases have probably had but little influence on them thru natural selection. However, one of the recently obtained clovers appears to possess an appreciable degree of resistance to this disease on a soil of medium productivity, and it may be that adapted varieties resistant to this disease will be found. That some plants are resistant (11) suggests the possibility that resistant varieties may be present in the state.

The *black-stem disease* (42), as previously noted, severely injured or killed many of the first-crop stems on the clovers during the spring of 1927, when a wet, warm season provided excellent conditions for the disease. It killed susceptible plants directly by destroying the stems, and injured the stems of the somewhat resistant plants in other clovers to such an extent that many died from inability to compete with healthier plants. On June 11, 1927, when Kentucky 101 was beginning to bloom, a few representative clovers were studied quantitatively with regard to the effect of this disease. The data obtained are given in Table 4.

The disease killed most of the first-crop stems of the French

TABLE 4. Effect of the "black-stem" disease on stand and yield of representative red clovers.

Clover	Stand* 3/21/27	Height (inches) 6/11/27	Ave. No. First-crop Stems Per Plant 6/11/27			Second-crop Stems Per Plant 6/11/27		Crown Buds Per Plant 6/11/27	Hay Yield, Ky. 101 Taken as 100	
			Good	Weak	Dead	Ave. No.	Average Length, Ins		First Crop	Second Crop
Kentucky 101	90	26	1.13	0.27	1.50	0.38	4.5	Numerous and vigorous	72	28
Minnesota 2585	85	26	0.73	0.92	2.05	3.50	8.0	Few and moderately vigorous	45	9
Roumanian 2423	52	20	0.87	0.83	2.90	0.77	8.3	Few and small	11	†
French 2584	20	16	0.12	0.43	3.23	3.00	11.0	Practically none	17	2

*90 stand = 315 plants to the square meter.
†Failure.

clovers when they were 2 to 4 inches long. The plants then developed their second-crop stems and produced a small yield of hay, as shown in Table 4. Few new stems developed after the first cutting, and the second hay crop was a failure. The disease killed fewer first-crop stems in the Hungarian and Roumanian clovers but killed or suppressed axillary buds. Since the percentage of killed first-crop stems was less than in the French, the second-crop stems developed to a less extent in the first crop and consequently produced less hay. A few plants made a very short new growth. The disease injured the bases of stems on the northern domestic clovers almost as much as on the Hungarian and Roumanian, but the upper portions were relatively free and consequently made more hay. However, the injury to most of the first-crop stems in the northern domestic lots resulted in premature development of the second-crop stems (Table 4), as in the foreign clovers, and they were cut in the first hay crop. It also injured and killed many stems of Kentucky 101, but plants of this clover were relatively resistant and matured enough stems for normal plant development; consequently the second-crop stems remained dormant until the first-crop stems were cut.

There has been no opportunity to study the relation of black-stem disease to clover failure since 1927 because other factors have destroyed stands of unadapted clovers before conditions became favorable for this disease. However, the fact that it practically destroyed European clovers in this test indicates that it sometimes contributes to clover failure in Kentucky, and the appreciable resistance of Kentucky 101 probably proves that it is frequently present.

Rhizoctonia is reported to have caused failures of entire clover fields in North Carolina (38), to have produced root rot of red clover in the field in Wisconsin, Utah, Minnesota, Ohio and Kentucky, and to have devastated flats of clover seedlings in the greenhouse (29). *Rhizoctonia violaceae* severely injures red clover in England, according to Ware (44).

The disease apparently has killed well-developed red clover plants in our greenhouse benches on several occasions, and

mature plants in Mr. H. H. Jewett's field insect cages on at least two occasions. It has been present in roots and crowns of dying and dead plants in our tests on several occasions, but whether parasitic or saprophytic was not established. The relation of Rhizoctonia to clover failures in Kentucky needs further study.

LEAF HOPPER INJURY

The potato leaf hopper, *Empoasca fabae* Harris, was recognized as a pest of red clover in 1892 (15), and as lethal under experimental conditions, in 1927 (16). Two years later it was suggested as a cause of clover failure (17, 26) in the United States.

Our experiments show that this insect can practically destroy field stands of foreign clovers, under favorable conditions, in Kentucky. The 1928-29 test was sown in a very thin stand of wheat, and all clovers made an excellent crop of hay the first year, which was cut July 12, 1928. Numerous hoppers then migrated into the clovers from a nearby alfalfa field, and severe injury to the new growth of European clovers soon became apparent. Most plants died before the middle of September, as indicated by the data in Table 5. A few Kentucky clovers, including 101, appeared practically uninjured, tho it is probable that they were somewhat stunted. Leaf hoppers caused more

TABLE 5. Reduction of stands of foreign red clovers, due largely to Empoasca fabae Harris.

Clover	Stand*		
	Original	7/23/28	11/7/28
		Percent	Percent
Kentucky 101	All excellent	98	90
Tennessee (1)**		98	90
Hungarian (1)		95	25
Roumanian (1)		95	25
Russian (3)		100	12
Polish (2)		100	30
French (5)		96	34
Italian (2)		92	25

*100 stand = 75 plants to the square meter.
**The number in ( ) indicates the number of lots of clover from each region averaged to obtain the stand. Each clover was grown in duplicate.

leaf injury to the Tennessee anthracnose-resistant variety than to Kentucky 101, but the plants were not killed.

The presence of southern anthracnose on domestic clovers in this test prevented any attempt to determine relative hopper resistance of domestic clovers from different regions. Jewett (18), however, has found that some domestic lots are injured more than Kentucky 101.

While the potato leaf hopper has not so markedly contributed to failure in other tests, there can be little question that it sometimes causes clover failures in Kentucky. The marked resistance of Kentucky 101* and its ability to recover after a severe attack (17), as compared with introduced clovers, is considered conclusive evidence that the insect is frequently injurious to clover in central Kentucky.

WINTERKILLING

Winterkilling probably is regarded as the usual cause of failure of European clovers north of the Ohio river. It seems to be almost the only cause of failure in the northern states (3, 8, 10, 23, 45), but is regarded as of somewhat less importance in central and eastern states, where the less hardy clovers, except Italian, may be satisfactory, especially in favorable winters (7, 9, 19, 27, 36). It is regarded as relatively unimportant in Virginia (47), but is reported as causing failures of French and Oregon clovers in West Virginia (28). Italian clover is unanimously regarded as least winter-hardy of the commercially available red clovers, and French as intermediate between Italian and most domestic clovers.

Northern domestic clovers have generally been most winter-hardy in northern states, and northern, central and eastern domestic clovers equally hardy in the central and eastern states. Northwestern clovers, on the whole, have been non-hardy. The few southern clovers reported have been generally quite hardy, even in northern states.

Winterkilling is an important cause of clover failure in Kentucky. Practically all tests furnished evidence of this fact, but

*This is Kentucky 1 in Jewett's report (17).

the conclusion is drawn mainly from results obtained during the winters of 1926-27 and 1927-28, when winterkilling was nearly the only cause of winter losses.

The winter of 1926-27 was about normal in temperature during December and January and above normal in Febraury, as shown in Fig. 2; consequently the amount of winterkilling that winter was probably representative of an approximately normal winter. The data in Table 6 show that northern, central, and southern domestic clovers stood the winter satisfactorily, but that the one northwestern clover (Oregon 2587) was injured considerably. The Italian clover was practically destroyed, and most plants in other European and the Chilean lots were killed. The second winter was hard on clover because of unusual fluctuations in temperature (Fig. 2) about the first of January, when an average minimum of —2° F. occurred on three successive days. There was no snow covering. The northwestern domestic clovers died within ten days. Northern and most southern

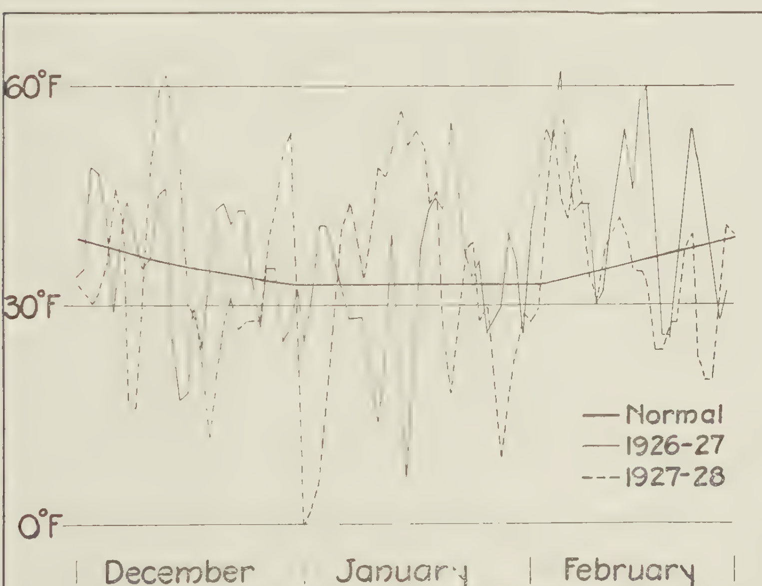

Fig. 2. Normal and average winter temperatures at Lexington. From the U. S. Weather Bureau records.

domestic clovers were injured severely, and most plants died before spring. Approximately one half of the plants in the central group of clovers were killed. Reduction in stand was small in Kentucky 101, but the plants were somewhat weakened. The extent of winterkilling in these clovers is shown in Table 6.

TABLE 6. Winter failures in red clovers from different regions.

Clover	Stand,* Crop of 1926-1927		Stands and Yields,** Crop of 1927-1928			Stand, Crop of 1928-1929		Stand, Crop of 1929-1930	
	12/4/26	3/21/27	Stand 12/1/27	Stand 4/2/28	Relative Yields	11/7/28	3/28/29	12/11/29	4/8/30
	%	%	%	%		%	%	%	%
Kentucky 101	100	90	95	87	100	90	75	95	95
Tennessee	(3)‡100	90	(1) 98	50	73	(1) 90	55	(3) 60	55
Other southern	(10)100	90	(4) 96	25	35	(21) 64	41	(52) 67	59
Central states	(3) 100	90	(2)100	53	74	(7) 50	16	(5) 56	49
Northern states	(2) 100	87	(3) 97	22	15	(6) 23	3	(6) 42	24
Northwestern states	(1) 100	77	(1) 94	Fail.	—	(6) 10	1	(12) 31	16
Chilean	(1) 95	30	(1) 96	Fail.	—				
Roumanian	(1) 100	52				(1) 25	5		
Hungarian	(2) 100	44	(1) 95	Fail.	—	(1) 25	5		
Russian			(1) 92	22†	Fail.	(3) 12	Fail.	(1) 45	20
German								(3) 40	5
Polish			(1) 93	2	Fail.	(2) 30	2		
French	(4) 98	22	(4) 93	Fail.	—	(5) 34	5	(4) 38	Fail.
Italian	(1) 86	3	(1) 95	Fail.	—	(2) 25	Fail.		

*100 stand = 350 plants to the square meter in 1926-1927 and 1927-1928 tests;
= 70 plants to the square meter in 1928-1929 test; and
= 100 plants to the square meter in 1929-1930 test.

**Winterkilling was the only factor reducing stand and yield in the 1927-1928 test. In other tests at least one other factor was concerned in reducing yields.

†The Russian clover probably was more severely injured than the spring stand indicates, as the plants died without making growth.

‡Numbers in ( ) indicate the number of lots averaged.

Winterkilling contributed to clover failures in 1928-29 and 1929-30, but other factors caused losses in stand during the fall or spring. It is therefore impossible to conclude that all winter loss was due to winterkilling. The potato leaf hopper and southern anthracnose were present in the summer of 1928 and may have been indirectly responsible for the killing of some plants during the following winter. However, Jewett (18) has

obtained experimental evidence that leaf hopper injury of a clover does not affect its winterhardiness in Kentucky. Losses in stand during the winter of 1928-29 were therefore probably due largely to cold weather and are so interpreted in Table 6.

The presence of southern anthracnose in the fall and crown rot in the spring made it difficult to determine the exact extent of winterkilling during the approximately normal winter of 1929-30. However, the plants that died during the winter showed no evidence of anthracnose injury, and it seems certain that the disease was a minor factor, if any, in winter mortality. Crown rot and perhaps an unidentified disease killed many plants before spring stands were determined. However, as previously noted, while practically all losses between fall and spring counts in most domestic clovers appeared to be due to these diseases, considerable winterkilling occurred in a few clovers. For example, as shown by the data in Table 3, crown rot and perhaps another disease killed 18 percent of the fall stand of Wisconsin 2, and winter injury 57 percent. Fall stands of French clover completely winterkilled during the middle of the winter, as suggested by the data in Table 6.

The causes of winter mortality of clover in tests prior to 1926 are not definitely known, for reasons previously mentioned, but winterkilling was a prominent factor in at least two of the four tests.

Additional evidence that winterkilling causes clover failure is available from seedings, for other studies, of Kentucky 101 and French 3, in isolated places. These clovers were sown in rows in 1929 and 1930. Both remained practically free of diseases thruout the first summer of each year. No winterkilling occurred in Kentucky 101 either winter. The 1929 seeding of French 3 completely winterkilled, but the 1930 seeding survived the winter without loss. The second winter was quite mild.

It is evident, therefore, that normal Kentucky winter weather nearly always destroys Italian clover and damages the stands of other European clovers sufficiently to make them unsatisfactory. Mild winters injure only the Italian, but subnormal temperatures kill most of the plants in all varieties of

European clovers. Winterkilling destroys northwestern domestic clover stands almost as extensively as European, but is destructive to northern clovers only in severe winters. Winter injury to central and southern clovers as groups is somewhat less extensive than to northern, but stands of many of these are unsatisfactory following severe winters. Winterkilling never has injured seriously Kentucky 101, and its outstanding superiority to other clovers in this respect is regarded as proof that winterkilling is a common cause of clover failures in central Kentucky and probably over most of the state.

It may seem unreasonable that clovers adapted to Kentucky are more winter-hardy in the state than clovers from northern states, where normal winter temperatures are from 10° to 35° F. lower. However, winter weather in Kentucky is very severe for plants that have no fixed rest period, as the following summary of the United States Weather Bureau temperature data at Lexington and Hopkinsville suggests:

	Lexington			Hopkinsville
	Normal	Normal Maximum	Normal Minimum	Normal
December	35.8	43.3	28.5	38.5
January	32.9	41.2	26.2	37.5
February	35.4	42.6	25.9	38.4

Winter temperatures fluctuate from below freezing to above the growing temperature. Consequently, since snow protection usually is infrequent and of short duration in Kentucky, a successful variety of clover in Kentucky must be able to withstand rapid changes from growing to sub-freezing and even zero temperatures.

DROUGHT

Farmers in Kentucky probably ascribe more clover failures to drought than to any other cause. Summer droughts are rather frequent and often severe and, as many clover failures occur at that time from disease and leaf hopper, it is but natural that they should be attributed to the drought. For example,

errors of this type were undoubtedly made in diagnosing the causes of failure of the 1926 crop on the soil experiment fields of the state. All fields were sown in 1925 with the same lot of seed, which, tho purchased as domestic clover, was largely foreign. It survived satisfactorily on the Lexington soil experiment field but failed during the latter part of the first summer and during the winter in another field at Lexington and on all other experiment fields in the state. Disease caused the summer failure at Lexington, but drought was given as the cause on the outlying soil fields.

These studies indicate that drought causes relatively few failures in Kentucky and that most of these occur during the first few weeks after seeding in a nurse crop. Severe droughts at that time are fatal to germinating and seedling clover. Well-established clovers, however, cease growth during droughts and may even lose practically all green parts except crown buds but resume growth when soil moisture conditions become favorable, if no disease or insect destroys the plants during the semidormant condition.

Kentucky 101 is drought resistant if it is well established before drought begins, and may remain semidormant for an undetermined period. It has survived a few droughts, including that of 1930, which was the severest since the establishment of the United States Weather Bureau Station at Lexington 43 years ago. The rainfall during this period of drought from March 1 to August 31 was 10.73 inches at Lexington, or 47 percent of normal, poorly distributed and accompanied by abnormally high temperatures. Aphids, grasshoppers and red spider also severely injured Kentucky 101, yet its stand in the 1929-30 test averaged 16 plants to the square meter on October 10, 1930. The normal second-summer loss of this clover is about 72 percent; the drought and other unfavorable conditions increased it 12 percent during 1930. A sufficient number of plants of several other domestic clovers survived for the second year to indicate that American clover as a crop possesses marked drought resistance.

The 1930 drought caused the failure of all clovers in the

1930-31 test. They were sown in wheat and either failed to germinate or perished during germination.

The resistance of European clovers to Kentucky droughts has not been determined because other factors always have caused their failure before or during such periods.

LOW SOIL PRODUCTIVITY

Roberts and coworkers (34, 35) present data from soil experiment fields thruout Kentucky which, tho not strictly comparable by fields because of a variable time factor, definitely show a relation between low soil productivity in the state and failure of clover in so far as its culture is attempted on such soils. Certain of their data which are summarized in Table 7 indicate that untreated soils in one half of the farming area of Kentucky are unsuited to clover. Most of these soils must be treated with lime and fertilizer for success with clover, altho limed and manured soils in the Purchase region, represented by the Mayfield soil field in Table 7, produce fairly well. While clover does not fail on the untreated soils of the area represented by the Russellville field, it yields satisfactorily only after the soil is lined or phosphated. Soil productivity is not a predominant factor in clover failure in the central and outer Bluegrass regions of central Kentucky represented by Lexington and Lincoln fields, respectively (Table 7), altho it may be an important factor in variation in yields.

The data do not show the productivity of the land actually farmed in each area, consequently they do not indicate the extent of clover failure that actually occurs on such soils because of low productivity; but a comparison of corn yields in the state with those on the unlimed and unfertilized plots on the experiment fields shows them to be about the same, and gives a basis for the inference that clover is likely to be a failure on general farm lands. Kentucky had an annual average corn yield of 27.3 bushels to the acre from 1914 to 1925, which is the same as a relative yield of 55 in Table 7. The clover yields on soil plots that produce this yield and less of corn is in no case as much as half a ton of hay, as shown in Table 7. A slightly higher yield of corn at Russellville is associated with somewhat more than

TABLE 7. Clover failures in Kentucky in relation to soil productivity as indicated by data from soil experiment fields.

Field	Percentage of State's Farming Area Represented*	No. of Crops Averaged		Plot Treatment** — Relative Corn and Clover Hay Yields†									
				LMSP		LM		MSP		M		O	
		Corn	Clover	Corn	Clover	Corn	Clover	Corn	Clover	Corn	Clover	Corn	Clover
Lexington	3.7	15	8	100	100	111	98	97	96	103	96	112	89
Lincoln	24.6	6	4	121	97	101	69	110	72	112	45	93	67
Russellville	18.7	11	9	95	76	79	61	75	51	64	32	58	29
Campbellsville	13.7	6	3	93	50	46	20	79	32	....	....	33	13
Mayfield	7.3	12	9	90	72	75	50	62	16	62	14	48	8
Greenville	20.2	10	9	82	55	71	32	71	40	51	14	37	7
Berea	5.6	13	7	88	45	79	14	76	14	56	9	29	2
Fariston	6.2	10	7	81	34	36	8	52	17	....	....	18	2

*Computed from Averitt's data (4).

**L = ground limestone; M = barnyard manure, except on the Lexington field where crop residues were used. Neither manure nor residues were used at Campbellsville or Fariston; SP = superphosphate; O = no lime, manure or fertilizer. A detailed statement of treatments is given in orginal reports (34, 35).

†100 = 49.3 bushels of corn and 4,620 pounds of clover hay.

half a ton of clover hay to the acre, but with this exception clover on soils of this productivity may be considered a failure; in fact it is not until soil productivity, as measured by corn yield, is about 50 percent above the state average that it produces a ton of clover hay to the acre. It appears, therefore, that outside the Bluegrass region crop lands are in too low a state of productivity to produce red clover successfully even if adapted strains were used. There is, of course, little reliable information on the extent of attempted culture on the poor soils of the state, without which it is impossible to estimate the probable number of failures due to poor soils; but the average clover yield in Kentucky in 1919, according to the United States census, was approximately 1.1 tons to the acre, which is almost two to four times that obtained from soils of average productivity for corn. In other words, clover apparently is grown in Kentucky on only the better agricultural soils.

The conclusion that clover culture is largely confined to the better soils of Kentucky is also supported by census data. A study of the distribution of the crop in the state, as given in

the 1924 census, shows that outside the Bluegrass region it is grown mostly in two regions (Fig. 3) of good soils. The southern region corresponds to the soil area represented by the Russellville field, where fairly good clover can be produced by liming or phosphating the soil (Table 7). The northern area in the western part of the state is located on recent alluvium and Pleistocene soils, which produce good clover when phosphated.

While most of the clover in Kentucky is grown on the better soils, observations have shown that the crop is often sown on soils too poor for consistent success. Practically all of these soils are marginal for the crop; if weather conditions are favorable they produce some hay or pasture; if weather conditions are unfavorable the clover is practically a failure.

Some conception of the nature of failures due to low soil productivity can be obtained from the data in Table 8, which were obtained from seven years' study on the Lexington and Berea soil fields, representative of the best and poorest soils of the state, respectively. These data show that the original stands

TABLE 8. Yields, heights and stands of red clover on soils of different productiveness.

Soil Field	Plot Treatment*	Relative Yields‡		Height of Clover at Harvest (inches) 1921-24, 1926-28	Stand 1921-24, 1926-28					
		Corn	1st Crop Hay		First Spring	Middle First Summer	Fall First Year	Spring Second Year	Middle Second Summer	Fall Second Year
					%	%	%	%	%	%
Lexington	LRSPK	100†	100†	24	100	69	32	28	20	8
	O	101	87	21	110	63	25	18	16	7
Berea	LMSPK	81	43	17	68	57	40	25	25	10
	O	26	2	5	47	35	11	6	4	1

*L = ground limestone; R = crop residues; M = barnyard manure; SP = superphosphate; K = potash; O = no lime, manure or fertilizer. For a detailed description of plot treatments, consult Roberts, Kinney and Freeman (35).

‡Fifteen corn and eight clover crops were averaged for Lexington yields, and thirteen corn and seven clover for Berea. As red clover has been sown in a mixture since 1925, only 1925 and prior data were averaged for the yields.

†100 = 54.3 bushels of corn, 4707 pounds of clover hay, 198 clover plants per square meter.

of established plants on the poorest soils were about half as good as those on the best soils; that the death rate before harvest in established stands on poorest soils is almost 1.2 times higher than on the best soils; that winterkilling on poorest soils is more than three times higher than on good soils; and that the plants grow about one fifth as tall on the poor soil as on the best soil. Further analysis of the data shows that the yield on the poorest soil is about one fiftieth that on the best soil, whereas on the basis of stand and height at harvest it should be one twenty-fifth. Limited data indicate that this is due principally to a difference in the number of stems per plant, those on the good soils averaging about 2.5 stems each, and those on the poorest soil averaging about 1 stem each.

There has been no opportunity to determine whether pathogenic organisms and insects are more injurious to clovers on poor soils than on good soils, but it is probable that leaf hoppers are more destructive on poor soils. Clover failures on poor soils are characterized by poor original stands, high mortality, especially during the winter, and poor growth of the plants.

DISCUSSION

Conclusions as to the chief cause of clover failure in other states usually have centered around one factor. The present studies show that many factors, acting singly or together, adversely affect unadapted clovers in Kentucky, eventually resulting in total or partial failure.

As pointed out in the consideration of these factors, injuries produced by some and possibly all of them vary with soil, weather, the pathogenic organisms present, and the strain of clover, making it impossible to single out any one factor as all important in the problem. Many years of intensive survey and study of clover failures thruout the whole state would be necessary in order to assign to the several factors their relative positions. However, these studies and observations indicate that certain factors are concerned with most clover failures and that others cause relatively little loss in the state.

It has been suggested previously that low soil productivity causes relatively few clover failures in Kentucky, primarily because, from experience, it has been found inadvisable to attempt to grow clover on poor soil. This factor, nevertheless, may actually cause as great an economic loss as any other or all other factors because its existence keeps clover from a majority of the farmed soils of the state, and the clover-failure problem cannot be regarded as adequately solved so long as the use of the crop is restricted by low soil productivity

Other factors causing clover failure in Kentucky annually destroy a large but undetermined acreage and reduce a larger acreage to poor stands. There is no means of arriving at any accurate estimate of the extent of these losses because of the lack of data showing the extent of complete failures for the state as a whole. However, a review of pertinent suggestive data and a statement of the general situation indicate that the annual economic loss from clover failure in Kentucky is high, both directly from the expense of seeding and indirectly from the absence of the crop from rotations.

This study shows that most clovers sown in the state fail to a greater or less extent when conditions are unfavorable, but the data are insufficient for conclusions as to the frequency of unfavorable conditions for clover in the state or as to the amounts of seed obtained from different regions, information necessary for any estimate of losses from clover failure. Nevertheless a rather accurate measure of the frequency of unfavorable conditions is obtained from data from the soil experiment fields on which commercial red clover was sown prior to 1928. These, which are presented in Table 9, show that nineteen of the ninety-seven crops, or about one in five, failed completely on the treated soils, and field notes indicate that more than half of the rest partially failed. It is highly probable, however, that more than one fifth of the clover sown annually in the state has failed, as the farmers have, on the whole, obtained their supplies of seed from more distant regions than has the Experiment Station, which atempts to obtain its seed in Kentucky or as near as possible. While there are no data giving the amount of clover

TABLE 9. Complete clover failures in the corn-soybeans-wheat-clover, and corn-wheat-clover rotations on soil experiment fields prior to 1928.

Experiment Field	No. Crops of clover of Unknown Adaptation Sown	Number of Complete Clover Failures	Causes of Failure Assigned by Field Observer
Lexington	15	3	Unknown disease and winterkilling
Russellville	10	1	Drought
Greenville	14	3	Drought and winterkilling
Lone Oak	9	1	Drought
Lincoln	6	1	Unknown, summer failure
Mayfield	13	2	Drought
Berea	11	3	Drought and winterkilling
Fariston	11	3	Drought
Campbellsville	8	2	Drought and winterkilling
Total	97	19	

seed from different seed-producing regions sown annually in Kentucky, or data that are more than suggestive of the amount of clover seed sown in Kentucky that is produced outside the state, the approximate amount of the latter may be estimated rather closely. Assuming that clover seed is sown on the mixed timothy and clover acreage at 5 pounds to the acre and on the pure clover acreage at the rate of 10 pounds to the acre, Kentucky uses about 33,000 bushels of seed. Census data indicate that Kentucky produce about 5,000 bushels of seed annually, or less than one sixth of its total sowing. Since most of the clover seed coming to Kentucky from other regions and much of that produced in Kentucky is unadapted to conditions within the state, and since apparently one-fifth of the annual seedings on good soils fail, it seems certain that at least 30,000 acres of clover fail annually in Kentucky from other causes than low soil productivity. Since losses from clover failures consist of the seed, labor and time, and failure to get the soil-building and conservation qualities which the crop would have provided, it is obvious that the total monetary loss in Kentucky from these types of clover failure is large.

It is impossible to evaluate the relative importance of the various causes of failure, but winterkilling is undoubtedly the

most frequent cause in Kentucky, being especially destructive to foreign and northwestern domestic clovers and frequently taking a considerable toll of northern domestic lots. Southern anthracnose may cause complete failures of most northwestern and northern, of many central and of a few southern domestic clovers, and severely injures European clovers. The extent to which it causes failure depends upon the distribution of the organism in the state from year to year. It does not seem to be generally present but rather appears to be introduced in some lots of seed. The potato leaf hopper is distributed thruout the state, but the extent to which it causes clover failures is not known. These tests prove that it is capable of causing failure of European clovers under field conditions, but it is rarely more than a contributing factor, since it is not fatal to most domestic clovers under field conditions. Crown rot is generally distributed in the state and may cause severe reduction in stands tho few failures. There is some evidence that it is of more importance than now considered.

It is possible that other causes of clover failure may exist in Kentucky, but whether they do or do not is of little agronomic importance, since they will not change the general aspect of the problem. In fact, the separate causes of clover failure, with the possible exception of poor soil, are incidental and would be of academic interest only if none but adapted clovers were grown in the state. Attempting to grow unadapted clovers, therefore, is the fundamental cause of clover failure in Kentucky.

SUMMARY AND CONCLUSIONS

Red clover failures have occurred in Kentucky since 1900. They caused reduction of over 50 percent in the clover acreage between 1899 and 1909. A few farmers state that failures began with the sowing of European clover seed. Seedsmen and farmers are pretty well agreed that such seed was first sown in Kentucky about 1900.

Studies have shown that clover failures in Kentucky are caused by poor soil, southern and northern anthracnose, crown

rot, potato leaf hopper, and winterkilling. Root rots and black-stem disease are at least contributing causes. Since the crop is sown but little on poor soils, relatively few complete failures occur as a result of low soil productivity, altho many partial failures can undoubtedly be asigned to it. Winterkilling is probably the most common cause of failures. Southern anthracnose contributes to many failures and sometimes is alone responsible for complete failure. The potato leaf hopper and crown rot are of considerable importance.

Winterkilling is usually severe on southern European, Chilean and northwestern domestic clovers. It destroys northern domestic clovers in severe winters. Southern anthracnose takes its greatest toll in northwestern domestic clovers and is severe on nothern domestic, European and Chilean lots. It kills many plants in clovers from central states. Northern anthracnose injures southern domestic lots. The potato leaf hopper is most destructive to European clovers. The black-stem disease is severe on European clovers and damages northern domestic lots to some extent. Crown rot is much more injurious to some clovers than others, but whether those from any given region are most susceptible cannot be determined from present evidence. Root rot varies in severity inversely with soil productivity rather than with the clover. However, there is evidence that resistant clover can be produced by selection.

The apparent solution of Kentucky's clover failure problem lies in the use of varieties which have become adapted to Kentucky conditions by years of natural selection within the state. None of the known causes of failure, except low soil productivity and root rot, appreciably injure these varieties.

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